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MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 85
Number 9

SEPTEMBER 1957

Closed November 15, 1957
Issued December 15, 1957

FORECASTING 700-MB. DEWPOINT DEPRESSION BY A 3-DIMENSIONAL TRAJECTORY TECHNIQUE

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[Manuscript received July 31, 1957; revised October 10, 1957]

ABSTRACT

Quasi 3-dimensional forecasts of 700-mb. dewpoint depression are made for periods up to 36 hours using observed 700-mb. charts and initial and 12-hr. forecast vertical motion charts from the JNWP Unit's "thermotropic model." Results show that moisture can be successfully forecast by this technique. Through establishment of a relationship between 700-mb. dewpoint depression, instantaneous vertical velocity, and large-scale weather, a forecast scheme is devised using forecast 700-mb. dewpoint depression and forecast vertical motion from the thermotropic model as arguments. Preliminary results of some experimental forecasts are favorable.

1. INTRODUCTION

This investigation was undertaken to determine how accurately moisture could be forecast using a quasi 3-dimensional trajectory technique. The moisture parameter selected was the 700-mb. dewpoint depression (T_s). This parameter is not dependent on total moisture and is considered to be a representative measure of the degree of saturation in that region of the atmosphere most associated with clouds and precipitation. The dewpoint depression of a parcel of air is assumed to change in a dry adiabatic process as a result of the vertical motions of the air parcel. The components chosen for the 3-dimensional trajectory were the 700-mb. wind, representing the mean isobaric component, and the vertical motion w produced by the Joint Numerical Weather Prediction (JNWP) Unit's "thermotropic model" [1], as representative of the mean vertical component. Forecasts were made for periods of 12, 24, and 36 hours from a 1500 GMT starting time.

In order to minimize forecast error, observed 700-mb. charts and initial and 12-hr. forecast w charts were used. The appropriate 700-mb. charts were used as perfect 12, 24, and 36-hr. forecasts. The initial (i. e., observed) w charts (1500 GMT) were used for initial and +24-hr. times in the trajectory computations. The 12-hr. w forecasts were used for +12 and +36-hr. times.

Briefly, the method consists of computing trajectories backward from forecast point to initial point, using the forecast 700-mb. charts in descending time order, to arrive finally at the initial chart. Hence a point is determined on the initial chart that will reach the station in the forecast time (12, 24, or 36 hours). The appropriate vertical motion is summed up over the route of the trajectory and applied to the initial dewpoint depression to get a forecast depression.

One hundred 12-, 24-, and 36-hr. forecasts of dewpoint spread were made using the 3-dimensional technique. Also, in order to have some measure of skill, forecasts were made from the same data using (1) persistence, and (2) 2-dimensional trajectories. In the former the initial dewpoint spread is presumed to hold for the entire forecast period (up to 36 hours). The latter technique is similar to the quasi 3-dimensional technique, except that the

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vertical motion component is omitted. Linear correlations between forecast and observed values for all three methods were obtained.

Finally a relationship was established between observed values of 700-mb. dewpoint depression, vertical motion, and the actual weather which serves as the basis of a forecast scheme. By plotting forecast values of T_s and w against time, a continuous forecast of large-scale cloudiness and precipitation (up to +36 hours with the thermotropic model) can be obtained.

2. PROCEDURE

Five stations were selected as forecast points; viz., Oklahoma City, Okla., Omaha, Nebr., Nashville, Tenn., Dayton, Ohio, and Washington, D. C. Forecasts of 700-mb. dewpoint spread were made for these stations for 12, 24, and 36 hours for 20 consecutive days from October 17 to November 5, 1956. Initial time was 1500 GMT.

In the trajectory computations, observed geostrophic winds were used throughout. By way of example, the procedure for construction of a 36-hr. trajectory is outlined: The trajectory is started on the +36-hr. 700-mb. "forecast" chart, by moving backward from forecast point. The +30-hr. point is transferred to the +24-hr. 700-mb. chart and the trajectory continued for 12 more hours to obtain the +24- and +18-hr. points. Pattern movement is closely considered since we are dealing with a 12-hr. trajectory segment using one chart. Next the +18-hr. point is transferred to the +12-hr. 700-mb. chart. Reverse motion is continued for two more 6-hr. periods, producing the +12- and +6-hr. points. Pattern movement is again considered. The +6-hr. point is transferred to the initial or 0-hr. 700-mb. chart and the final 6-hr. reverse motion accomplished. This produces the location of the intitial point. Air at this point can be expected to reach the forecast point in 36 hours.

The dewpoint spread at the initial point is determined by interpolation from a carefully performed dewpoint spread analysis. The effects of vertical motion on this dewpoint spread are now determined by first summing up the vertical motion components from the 12-hr. interval w charts. This is done by adding (1) w at forecast point on the +36-hr. chart; (2) $2w$ at +24-hr. point on +24-hr. w chart; (3) $2w$ at +12-hr. point on +12-hr. chart; and (4) w at initial point on the initial w chart. Doubling of w on the +24- and +12-hr. charts is due to the fact that these charts represent two 6-hr. advection periods. We now have a total of six 6-hr. w components. These are added and the total divided by 36 to get the net w effect per hour. This amount of vertical motion acting for 36 hours will then change the dewpoint spread a certain amount. The spread will decrease with positive vertical motion, increase with negative vertical motion. The relation between change in dewpoint depression and vertical motion in the vicinity of the 700-mb. level was determined from a skew T–log p adiabatic diagram. A scale was drawn up which conveniently gives the change in T_s due to vertical motions acting for periods of 12, 24, and 36 hours.

TABLE 1.—*Linear correlation between forecast and observed 700-mb. dewpoint depression. F_p=persistence forecast, F_2=2-dimensional forecast, and F_3=quasi 3-dimensional forecast*

	F_p	F_2	F_3
r (12 hr.)	0.60	0.64	0.77
r (24 hr.)	.31	.42	.75
r (36 hr.)	.07	.23	.56

The 24- and 12-hr. trajectories were done analogously to the 36-hr. ones but were correspondingly simpler.

The vertical motion from the thermotropic w charts was used without alteration in the initial 3-dimensional computations. This theoretically applies at 500 mb. However, in view of the assumptions in thermotropic theory [2] and the approximate trajectory and vertical motion summation technique, it was decided at first that little if any benefit could be gained by reducing the thermotropic w to 700 mb. Later the 24-hr. forecasts were recomputed using a 700-mb. w obtained from the 500-mb. w by assuming a parabolic distribution of vertical motion with height.[2]

One other procedural point of interest is the limit placed on the 700-mb. dewpoint depression. This was arbitrarily set at 15° C. and applies to both initial and forecast values. The reason for this is that when the depression ranges up near 15°, a missing (or "motor-boating") dewpoint is usually reported. At the other end of the range, the lowest dewpoint spread was zero. Values calculated to be negative were considered to be zero.

3. RESULTS

The results are best shown by means of the correlation table (table 1). Recall that these results were obtained using observed 700-mb. charts and observed and 12-hr. forecast w charts. Thus they represent something near the upper limit of proficiency for the manual 6-hr. step trajectory technique. All forecast spreads were verified by 700-mb. observed spreads, with the arbitrary 15° C. limit applied.

Table 1 shows the distinct advantage in using the vertical motion. The correlation for 24-hr. forecast using 700-mb. w was 0.71, which is not significantly different from that obtained using 500-mb. w.

One other correlation was computed, suggested by the work of Hertzberg [2]. Hertzberg developed a rain or no-rain forecast technique for Washington, D. C., which consists of applying the JNWP Unit's forecast vertical

[2] Note on thermotropic vertical motion: Thermotropic theory [1] assumes a vertical motion distribution where the vertical mass transport ($\rho g w$) is 0 at the top of the atmosphere and over flat terrain and is a maximum at the level of nondivergence, taken to be about 500 mb. Terrain-induced vertical motion is included but the effect is damped out above the terrain. Vertical motion for a level different from 500 mb. can be computed by assuming a parabolic profile, with the vertical mass transport 0 at 200 mb. and sea level, and with a maximum at about 500 mb. Using 200 mb. as a zero level permits the use of a linear height axis. Thus the zero levels are at 0 ft. and about 38,000 ft., the maximum $\rho g w$ level about 19,000 ft. Such a relation was worked out and scales drawn up to give vertical motion at any level in terms of thermotropic 500-mb. w.

motion (up to 36 hours) to the most moist 150-mb. layer of the current (corresponding to numerical forecast initial time) Washington, D. C., sounding. By means of graphs statistically determined, a rain or no-rain forecast is obtained. For purposes of comparison an adaptation of this technique was made by taking the initial dewpoint spread at forecast point and applying the forecast vertical motion to it. The resulting correlation between forecast and observed was 0.54. This compares with 0.42 for a 2-dimensional forecast and 0.75 for the 3-dimensional forecast.

4. OPERATIONAL FORECAST SCHEME

A preliminary relationship between 700-mb. T_s, w, and weather was established by plotting about 250 observed values of 700-mb. T_s (0300 and 1500 GMT), w, and corresponding observed weather. These data were obtained primarily from the trajectory study. The weather was broken down into four categories; viz, (1) precipitation, excluding scattered showers and stratus drizzle; (2) broken to overcast middle and low clouds, excluding fog and stratus; (3) scattered middle and low clouds, with same exclusions as (2); (4) high clouds or clear.

The relationship between the variables showed reasonable correlation, but due to the smallness of the sample some subjective smoothing was necessary to produce isolines delineating the weather categories. The resulting nomogram is shown in figure 1. The nomogram is entered with forecast 700-mb. dewpoint depression (T_s) and forecast vertical motion. The weather at their intersection is determined by the envelopes. In principle, a forecast of large-scale cloudiness and precipitation can be obtained for any combination of forecast T_s and w. On this basis a forecast scheme was devised using JNWP Unit's thermotropic forecast charts. Since the thermotropic model produces 1000- and 500-mb. level forecasts, the obvious choice for the 2-dimensional trajectory component was 750 mb., obtained by taking one-half of the sum of the two forecast levels. The 750-mb. charts were obtained by means of an electronic computer (IBM 701 EDPM).

Experimental forecasts were started on March 31, 1957 for Washington, D. C. Initially the trajectories were computed in 6-hr. steps as described in section 2, but starting on April 10 the trajectories were computed on the IBM 701 electronic computer from the thermotropic history tape. This was done in 1-hr. steps thereby increasing the accuracy of the trajectories. Also the trajectories were done for the intermediate times of 30 and 18 hours.

The forecast values of 700-mb. T_s (quasi 3-dimensional) for 12, 18, 24, 30, and 36 hours were plotted against time. The initial (observed) value of T_s at forecast point is also plotted and a smooth curve drawn. Initial and forecast w for 12, 24, and 36 hours is plotted against time and a smooth curve drawn. By means of the T_s–w–weather relationship, a forecast of clear, cloudy, partly cloudy, or precipitation is obtained for the entire 36-hr. period.

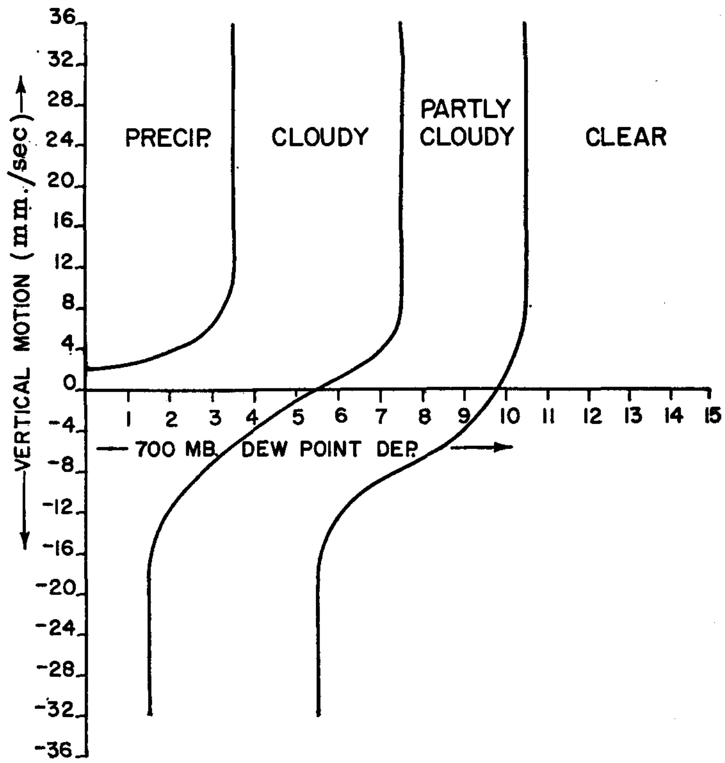

FIGURE 1.—Nomogram used for determination of weather categories, giving weather as a function of vertical motion in millimeters per second and the 700-mb. dewpoint depression in degrees Celsius. Enter nomogram with 700-mb. dewpoint depression and vertical motion and forecast weather indicated within envelopes.

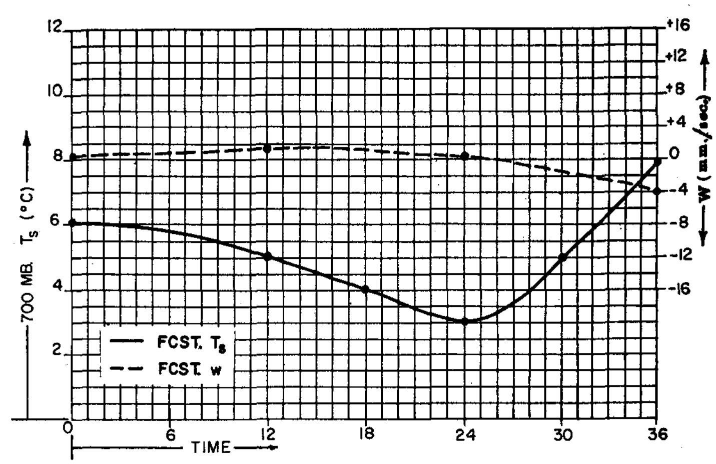

FIGURE 2.—Forecast example using machine-computed trajectories from 1-hour time steps. Forecast made from 1500 GMT, April 28, 1957. Weather forecast: Cloudy most of period, becoming partly cloudy evening of 29th.

Figure 2 is an example of a typical forecast. In this example the dewpoint depression is forecast to decrease gradually for the first 24 hours and then to increase gradually. The vertical motion is forecast to become slightly positive for the first 12 hours, to return to 0 at +24 hours, and to become negative by 36 hours.

The observed dewpoint depression decreased in the first 24 hours to the value forecast (3), but then increased more rapidly than forecast to a value of 15 (vs. a forecast of 8).

The actual vertical motion curve showed an increase to +7 mm./sec. after 24 hours vs. a forecast of 0, and then a decrease to −13 mm./sec. by 36 hours vs. a forecast value of −4 mm./sec. The "observed" value at +36 hours was obtained from the next day's 12-hr. forecast

The weather forecast was: partly cloudy for the first few hours, cloudy for most of the remainder of the period, partly cloudy near the end of the period. The actual weather sequence was: clear initially, becoming cloudy in the first few hours. Cloudiness prevailed for most of the period followed by rapid clearing at the end. The clearing occurred behind a cold front which passed Washington, D. C., at about +22 hours.

In this example the trends of dewpoint spread and w were forecast correctly. The subsidence toward the end of the period was under-forecast, which accounts in part for the error in forecast T_s at +36 hours.

The accuracy of the forecast depends primarily on the accuracy of the thermotropic charts and the T_s–w–weather relationship. The latter is suspect at this time since it was obtained with a small sample. Its form is probably essentially correct but more data are necessary to put the relationship on a statistically reliable basis.

Some preliminary results of the forecasts have been computed. Thirty cases have been summarized, of which 22 had the advantage of machine-computed trajectories. The forecasts were obtained between March 31 and May 9, 1957.

The verification results are broken down into four categories; viz:

(1) Linear correlations of T_s forecast vs. T_s observed, for the 12-, 24-, and 36-hr. forecasts. As with the basic study the three types of forecasts (persistence, 2-dimensional, and quasi 3-dimensional) are compared. Results are shown in table 2.

(2) Linear correlation of forecast 24-hr. w vs. observed w for forecast point (Washington, D. C.). This is used as an indicator of thermotropic forecast quality. Result is included in table 2.

(3) Table (table 3) showing 24-hr. forecast observed weather using the four weather categories described previously.

(4) Table (table 4) corresponding to (3) above, where the weather forecasts were made using observed (verifying) T_s and w in place of the 24-hr. forecast values. This gives an indication of the accuracy of the weather indicator.

TABLE 2.—*Linear correlation between forecast and observed 700-mb. dewpoint depression. F_p=persistence, F_2=2-dimensional (no w), F_3=quasi 3-dimensional. Included is the linear correlation between 24. hr. forecast vs. observed w.*

	F_p	F_2	F_3
r (12 hr.)	0.50	0.69	0.80
r (24 hr.)	.35	.07	.63
r (36 hr.)	.08	.49	.47

r (w_f vs. w_o)=0.81

TABLE 3.—*24-hr. forecast vs. observed weather*

	Observed: Precipitation	Broken to overcast (middle and low clouds)	Partly cloudy (middle and low clouds)	Clear or high clouds
Forecast: Precipitation	1	2	0	1
Broken to overcast (middle and low clouds)	1	4	2	1
Partly cloudy (middle and low clouds)	0	4	0	1
Clear or high clouds	0	1	3	9

TABLE 4.—*Forecast vs. observed weather using observed T_s and w as forecast values. (Same cases as table 3.)*

	Observed: Precipitation	Broken to overcast (middle and low clouds)	Partly cloudy (middle and low clouds)	Clear or high clouds
Forecast: Precipitation	3	4	0	0
Broken to overcast (middle and low clouds)	0	5	1	0
Partly cloudy (middle and low clouds)	0	1	4	1
Clear or high clouds	0	1	1	9

The results in table 2 show that the 3-dimensional forecasts compare favorably with those obtained in the basic study (see table 1). The lower correlations for 24- and 36-hr. forecasts are to be expected using forecast charts. The results of the 2-dimensional forecasts are perplexing in that the 24-hr. result was very poor whereas the 36-hr. result was slightly better than the corresponding 3-dimensional forecast. This may be due to the smallness of the sample or perhaps the peculiarities of the weather regime during the period the forecasts were made. The persistence results seem more logical and compare favorably with those of the basic study.

The quality of the thermotropic forecasts is the major factor affecting the forecast results. By subjective criteria, the thermotropic forecasts for the 30 cases studied were, in general, good. The correlation between 24-hr. forecast and observed w of 0.81 confirms this. Note that this is only the w correlation for forecast point, and does not refer to the mean w used to alter the initial dewpoint spreads.

The verification of the weather forecasts is shown in table 3. The forecast weather was obtained from forecast T_s and w by means of the weather indicator (fig. 1). The exclusions to the categories are the same as explained previously. The results shown in the table are fairly good. In general, the forecast is only one category from the observed.

In order to test the accuracy of the weather indicator for these cases, the observed values of T_s and w were used to obtain the forecasts. Results are shown in table 4. These are better than the corresponding results using forecast T_s and w, but still show discrepancies.

One thing indicated by the table is that the requirements for precipitation should be tightened. Three of the four cases of forecast precipitation which verified cloudy were just within the precipitation zone on the weather indicator (fig. 1).

5. CONCLUSIONS

The basic results show that the methods developed for forecasting middle atmosphere moisture are sound. The forecast moisture parameter (700-mb. T_s) along with the forecast vertical motion can then be used to obtain a forecast of large-scale cloudiness and precipitation. Preliminary results of experimental weather forecasts using the methods developed are favorable. It is of interest to note that in a recent vertical motion study at Pennsylvania State University [3], a primary conclusion was that an objective system of weather forecasting based on vertical motion should include moisture as an additional independent variable.

The forecast scheme can easily be adapted for machine computation of area weather forecasts. This is now in the planning stage.

The basic machine method under consideration is to compute the forecast dewpoint spread at each grid point by horizontal advection plus a vertical motion effect. This would be done hourly. By using the T_s–w– weather relationship, forecasts of large-scale cloudiness and precipitation could be printed out at desired times.

Results with machine-computed trajectories should be superior to those obtained by the manual technique, primarily because the vertical motion effect can be considered each hour, rather than as 6- or 12-hr. averages. Furthermore, area forecasts based on large-scale vertical motion should be more successful than point forecasts, since the weather at a particular point may be influenced by local or small-scale effects.

ACKNOWLEDGMENTS

This project was originally started by Capt. Earl C. Kindle, formerly of the JNWP Unit, now with Scientific Services, Air Weather Service. Capt. Kindle developed the method of forecasting 700-mb. dewpoint depression by trajectory plus vertical motion effect, and made some of the initial calculations.

Thanks are due Dr. George P. Cressman, Director, JNWP Unit, for many valuable suggestions during the course of this project. Thanks are also due Lt. Edward Carlstead, USN, and Mr. A. William McKnight, both of the JNWP Unit, for help in computation of the results, and in preparation of the experimental forecasts.

Finally, the writer is indebted to Lcdr. William E. Hubert, USN, JNWP Unit, who wrote the trajectory code for the IBM 701 EDPM. This code was used to obtain the 750-mb. trajectories for the experimental forecasts.

REFERENCES

1. P. D. Thompson and W. L. Gates "A Test of Numerical Prediction Methods Based on the Barotropic and Two-Parameter Baroclinic Models," *Journal of Meteorology*, vol. 13, No. 2, Apr. 1956, pp. 127–141.
2. M. H. Hertzberg, "Objective 36-Hour Precipitation Forecasts for Washington, D. C.," Appendix C of "Numerical Weather Prediction," *NAVAER* 50–1P–541, Department of the Navy, Washington, D. C., June 1956.
3. Albert Miller et al., "Vertical Motion and the Weather," *Scientific Report* No. 2 on Contract AF 19(604)–1027, Pennsylvania State University, College of Mineral Industries, Dept. of Meteorology, 1957.